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Complex study of foliage nutrient status in ash fertilized Scots pine stands in Lithuania

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ABSTRACT: In Lithuania, a typical Scots pine stand under the influence of wood ash and nitrogen fertilization, containing different treatments and the control, was analyzed. The study aim was to interpret the foliage and soil analyses, and to find possible indications in the soil-plant relation in the stand. The analyses of the foliage nutrient status in the Scots pine stand when wood ash with/without N was recycled to the forest showed that the significance analyses of changes in the nutrient composition in the soil and needles were the best initial tool for the response evaluation. The comparison of the nutrient concentrations with optimal amounts, critical levels of deficiency or target levels for ratios to N, and applied graphical analyses, could also provide possible indications in the soil-plant relation.

Keywords: Scots pine needles; wood ash; nitrogen; foliage; nutrients

The main fertilization trials in Lithuania were carried out for several decades in Scots pine stands growing on sandy soils, mostly in nurseries, or on poor deflated Arenosols. It has long been known that the most effective impact on pine stands was found after the application of nitrogen (N) fertilizers. But as the fertility of the site improves, N fertilization alone will no longer increase growth because other nutrients begin to limit growth. Thus, the general aim of forest fertilization is to improve the growth of a tree stand by adding the complex of nutrients, the lack of which is limiting the growth (Saarsalmi, Mälkönen 2001).

At present, we raise the idea that the expansion of the consumption of forest biomass for bioenergy causes an increased export of nutrients from the forest because the exported branches, needles and tops have higher concentrations of nutrients than the stem wood (Jacobson et al. 2000; Mikšys et al. 2007). In the near future, the extraction of forest harvest residues (branches, needles, tops) for forest fuel will surely increase. Each year, about 30% (close to 0.8 million m^3) more biomass can be used as fuel wood, which is now left on clear felled sites (Kairiūkštis, Jaskelevičius 2003). It is important when talking about the reduction in anthropogenic emissions of greenhouse gasses, the signed Kyoto Protocol, and the 8% reduction in emission against the 1990 level for 2008–2012.

Compensatory wood ash fertilization may be required to prevent negative effects associated with nutrient deficiencies caused by harvesting. Wood ash could improve the mineral soil with almost most of the nutrients: calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P), except nitrogen (N). In regions with poor sandy soils, compensation with N fertilizers may also be required. The major reasons for the wood ash recycling would then be to return essential mineral nutrients to the forest and to counteract increasing soil acidity – as it produces a strong liming effect, and buffer capacity of the soil (Ohno, Erich 1990; Ljung, Nordin 1997; Eriksson 1998; Levula et al. 2000; Saarsalmi et al. 2001). Therefore, it was even found that compensatory wood ash fertilization causes an increase in the stand growth (Pärn 2005; Saarsalmi et al. 2006; Ozolinčius et al. 2007b).

Nevertheless, before it is possible to expand the wood ash fertilization in Lithuanian forests, the treatment procedures and environmental consequences need to be clarified. The influence on the chemical composition of soil and plants was mostly studied abroad (Bramryd, Fransman 1995; Williams et al. 1996; Eriksson 1998; Kellner, Weibull 1998; Moilanen, Issakainen 2000; Pärn 2005; Saarsalmi et al. 2005; Mandre et al. 2006). In 2002 such a type of integrated experiment was started in Lithuania, and the different parts of the Scots pine ecosystem (soil, soil solution, ground vegetation, trees) were studied separately (Ozolinčius et al. 2005; 2006; 2007a,b). However, the possible causes of the changes in the foliage nutrient status have not yet been identified as a problem. Though, it is not usually possible to make a reliable diagnosis of balanced nutrition in the trees without the complex nutrient analyses (Thelin et al. 1999; Saarsalmi, Mälkönen 2001). It is well known that plants growing in natural conditions could regulate nutrient concentrations and, therefore, sustain quite a constant ratio between N and other nutrients (Ingestad 1979; Linder 1995). The compensating wood ash and N fertilization applied in the forests saturates the soil with additional amounts of various nutrients. Like usual fertilizers, this application could either cause the imbalance of elements in the soils or improve the nutrient status and accelerate the tree growth. The deficiencies of different nutrients or, generally, inadequate nutrition by one/some of them could be caused by several factors: fertilizer type or method of application, fertilization during unsuitable weather or to plots with a high risk of leaching or even inherent poor site properties (Wilson, Farrell 2007). The latter two reasons could be taken as a pre-study statement because all the results for this paper were collected from the stand growing on poor-in-nutrients Arenosols with a high risk of leaching.

The relation between the concentration of nutrients in the plant tissue and the plant growth could be treated as a very general statement (Thelin et al. 1999). It was already found that the nutrient deficiency could reduce the growth by 10%. The differences between various nutrients could also give a different response. For example, the deficiency of N and P causes a faster and direct growth reduction compared to other nutrients.

The main goal of this study was to analyze the foliage nutrient status in a Scots pine stand when wood ash with/without N was recycled to the forest. More specific aims were to interpret the foliage and soil analyses, and to find possible indications in the soil-plant relation in Scots pine stands.

MATERIAL AND METHODS

Wood ash and nitrogen experiment, containing different treatments and the control, was conducted for the complex analyses of foliage nutrient status in a Scots pine stand in Lithuania.

Site. The study site lies in the SW part (54°55'N, 23°43'E) of Lithuania in a common Scots pine stand for the country. Mean annual precipitation is 686 mm and mean annual temperature is 6.5°C. The

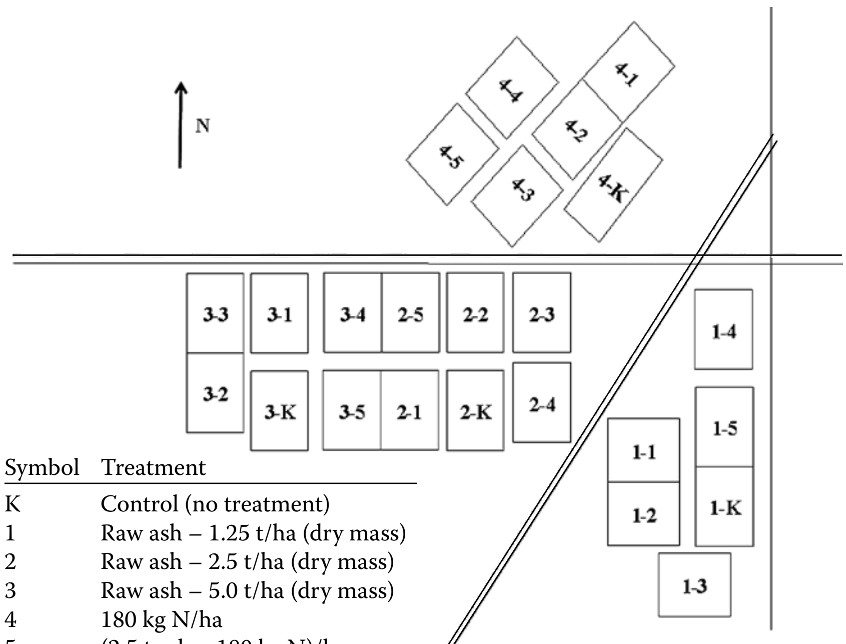


Fig. 1. Experimental design of the wood ash fertilization experiment that started in Kačerginė forest district of the Dubrava Experimental and Training Forest Enterprise, June 2002

average tree height was 14.8 m and the mean diameter at breast height was 14.3 cm at the start of the experiment. The forest type is *Pinetum vacciniosum*, and the forest site is named as Nb – oligotrophic mineral soil of normal moisture according to the Lithuanian classification. The experiment was set up in the first generation Scots pine (*Pinus sylvestris* L.) stand, planted in 1964, on a sandy limnoglacial plain overlying old fluvioglacial sands in 2002. The soil was classified as *Haplic Arenosol* (ISSS-ISRIC-FAO 1998).

The experiment consisted of 24 plots (25 × 20 m^2) grouped into 4 blocks with 6 treatments in each block. The following treatments were applied: 1.25; 2.5 and 5 t wood ash/ha, N fertilizers – 180 kg N/ha, 2.5 t wood ash/ha together with 180 kg N/ha, and the untreated control (Fig. 1). In this study, the results of the maximal wood ash amount (5 t/ha) and both treatments with N fertilizers were mostly analyzed.

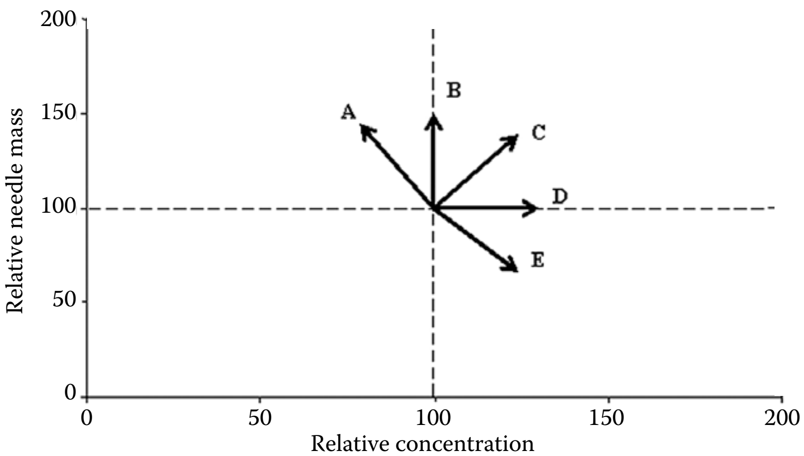
The raw wood ash of known chemical composition and N fertilizers (ammonium nitrate) were applied in the stand in June 2002.

Sampling and analysis. Soil sampling was carried out twice, in October 2002 and September 2004, respectively, five months and about 2 years after treatment. From each plot, 20 soil sub-samples were collected from the O horizon (forest litter) and the mineral topsoil (0–5 cm). The soil samples were pooled to produce one composite sample from each depth and plot. The soil chemical analyses were performed according to the methods described in the ICP-Forests manual (UN/ECE 2003). The concentration of total N was analyzed according to the Kjeldahl method, total Mg and Ca – with atomic absorption spectrophotometer (AAS), K – with flame photometer and P – using standard colorimetric methods.

Soil solution was sampled at 20 cm and 50 cm depths by tension lysimeters (P80 ceramic cups by Ceramitech) in April–May, November of 2003, April–May, September of 2004, and April–May of 2005. The lysimeters were installed systematically in all plots. Altogether 144 tension lysimeters were installed: 6 in each plot (3 replications per depth and plot). The lysimeters were de-pressurized to –70 kPa for the suction of soil solution. The soil solution samples from both depths were analyzed for NH_4, NO_3, P, K ions. NH_4^+ was determined by a colorimetric method (hypochlorite), NO_3^- spectrometrically using sulphasalicylic acid. P was determined as molybdate-reactive P by a colorimetric method. K^+ concentration was measured with flame photometer (UN/ECE 2002).

Needles were sampled from 5 Scots pine trees in each plot. Sampling trees belonging to Class II according to the Kraft classification were chosen. The current year and one-year-old needles were sampled from the 5–7th whorl from the upper ⅓ of the crown in October 2002 and September 2004. The needles were removed from the twigs and distributed into two groups according to the age: current year and one-year-old needles. Before analysis, equal quantities of each of the five samples from each plot were pooled to form a composite sample and were dried at 60°C for 24 hours (UN/ECE 2000).

The concentrations of N, P, K, Ca and Mg were analyzed in the current and first year needles. Total



Shift	Concentration in the needles	Needle mass	Diagnosis
A	Decreases	Increases	Element is sufficient and diluted
B	Unchanged	Increases	Element is sufficient
C	Increases	Increases	Element is growth limiting (deficiency)
D	Increases	Unchanged	Element is stored (luxury consumption)
E	Increases	Decreases	Element is toxic

Fig. 2. The modified graphical representation of diagnoses arising from changes in the needle nutrient concentration and needle mass after treatment. Response vectors radiate out from untreated control (100, 100) to treated conditions, which are plotted as percentage of the control. The length of the vectors originally shown on the scheme is ignored here (Timmer, Morrow 1984)

Table 1. The chemical composition of wood ash applied in a field experiment

Macronutrients	(g/kg)	Heavy metals	(mg/kg)
P	2.15	Cr	9.51
K	5.29	Cd	0.62
Ca	72.0	Pb	4.53
Mg	9.45	Ni	8.05
		Cu	13.1
		Zn	73.7

N was analyzed by the Kjeldahl method. Total P was determined by the colorimetric method, total K by flame photometry, and Ca and Mg by AAS. Methods described by Lichtenthaler (1978) were used for chlorophyll assessment.

Data analyses. The ratios of nutrients in the needles of Scots pine were compared to the mean values calculated by Vaičys et al. (1979), Šleinys (1986), Linder (1995) and Braekke et al. (1998). Needle nutrition data were also evaluated using critical levels of deficiency (Vaičys et al. 1979; Abrahamsen 1980; Chapin, Van Cleve 1989; Braekke 1996). The method of Simplified Graphical Vector Analyses (Timmer, Morrow 1984; Ingerslev 1998; Thelin 2000) was used for the examination of the tree response to a treatment (effects of treatments on needle mass and needle nutrient concentrations relative to the control) (Fig. 2).

Differences between treatments in needle mass, nutrient concentrations and ratios to N, and soil parameters were evaluated using ANOVA followed by the *t*-test. The correlation analyses indicated the direction of a linear relationship between two variables, i.e. between the nutrient concentration in needles and soil or soil solution.

RESULTS AND DISCUSSION

Chemical changes in needles

The chemical composition of Scots pine needles was mostly changed when pure nitrogen (180 kg N/ha) and wood ash together with nitrogen (2.5 t ash + 180 kg/N/ha) were applied to Scots pine growing on Arenosols. Initially, even 5 months after the treatment, N concentrations in the current year needles increased significantly ($P < 0.05$) 1.2–1.3 times, in the first year needles by about 6–15% compared to the control (Table 2). The main changes were found in the N treatment where N concentration increased by 3.75 g N/kg and amounted to 17.65 ± 0.45 g per N/kg. Similarly, both treatments with N fertilizers increased the concentrations of other nutrients in the current year needles: P by 6–17%, K 17–28%, Ca about 40% and Mg 15%.

Wood ash increased only the concentration of Ca in the current year needles, and it was by 25% higher than in the control.

In all treatments, smaller differences or no effect was found in the chemical composition of the second year needles. The data showed that only the current year needles could response to the fertilization effect during the period of active vegetation.

There were only few significant changes in the data obtained 2 years after the application of neither wood ash nor N fertilizers (Table 2). The current and first year needles remained affected by N fertilization, and the values of N concentration were higher by 14–19% compared with untreated plots. There was a tendency that N fertilization intensified the uptake of other nutrients: slightly increased concentrations of P, K and Ca were detected. No influence of the ash

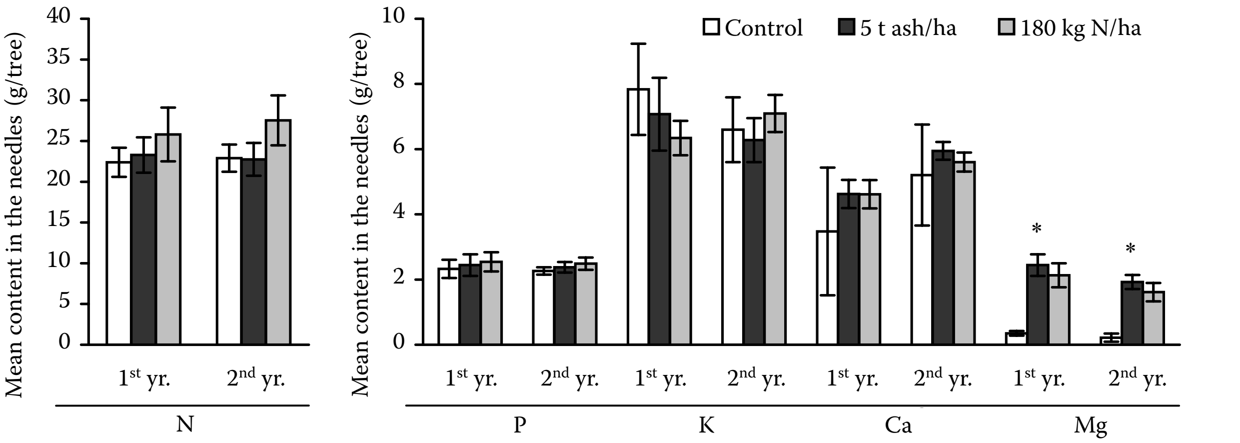


Fig. 3. Mean contents of some nutrients in the current year and first year needles 2 years[1] after the application of wood ash and N fertilizers ([1]the needle mass data for mean nutrient content calculations 5 months after the treatment was not available). One asterisk (*) denotes that significance is given with respect to the ash and N treatment

Table 2. Effects of wood ash and N treatment on the mean concentrations of different elements in the current and first year needles of Scots pine. Mean values are followed by SE, n = 3. Evaluation of treatment effects by ANOVA. The values followed by the same letter in each column and different measurement at different time after treatment are not significantly different from each other

Treatment	N		P		K		Ca		Mg	
	(g/kg)									
5 months after application	Current year needles									
Control	13.90 ± 0.77	a	1.20 ± 0.06	a	2.73 ± 0.37	a	1.80 ± 0.16	a	0.92 ± 0.06	a
5 t ash/ha	13.78 ± 0.50	a	1.35 ± 0.06	ab	2.78 ± 0.43	a	2.61 ± 0.22	b	0.91 ± 0.04	a
180 kg N/ha	17.65 ± 0.45	c	1.40 ± 0.09	b	3.48 ± 0.06	b	2.59 ± 0.29	b	1.02 ± 0.05	ab
(2.5 t ash + 180 kg N)/ha	16.18 ± 0.43	b	1.28 ± 0.09	ab	3.18 ± 0.27	ab	2.46 ± 0.14	b	1.07 ± 0.03	b
	First year needles									
Control	14.18 ± 0.45	a	1.18 ± 0.07	a	2.55 ± 0.22	a	2.93 ± 0.20	a	0.76 ± 0.04	a
5 t ash/ha	13.53 ± 0.39	a	1.13 ± 0.06	a	2.65 ± 0.16	a	3.65 ± 0.55	ab	0.82 ± 0.11	a
180 kg/N/ha	16.25 ± 0.89	b	1.05 ± 0.03	a	3.03 ± 0.32	a	3.73 ± 0.42	b	0.75 ± 0.09	a
(2.5 t ash + 180 kg/N)/ha	15.10 ± 0.47	ab	1.18 ± 0.10	a	2.48 ± 0.23	a	4.98 ± 1.57	b	0.79 ± 0.03	a
2 years after treatment	Current year needles									
Control	13.90 ± 0.35	a	1.43 ± 0.03	a	4.77 ± 0.41	b	2.23 ± 0.45	a	1.23 ± 0.12	a
5 t ash/ha	14.43 ± 0.66	a	1.50 ± 0.06	ab	4.33 ± 0.30	b	2.87 ± 0.12	b	1.50 ± 0.06	b
180 kg/N/ha	15.87 ± 0.48	b	1.57 ± 0.03	b	3.93 ± 0.07	a	2.87 ± 0.18	b	1.30 ± 0.10	a
(2.5 t ash + 180 kg/N)/ha	n.d.*		n.d.		n.d.		n.d.		n.d.	
	First year needles									
Control	14.43 ± 0.37	a	1.43 ± 0.07	a	4.10 ± 0.21	a	3.33 ± 0.38	a	1.00 ± 0.15	a
5 t/ash/ha	14.30 ± 0.35	a	1.50 ± 0.06	ab	3.93 ± 0.07	a	3.77 ± 0.19	a	1.21 ± 0.06	a
180 kg/N/ha	17.23 ± 0.20	b	1.57 ± 0.03	b	4.47 ± 0.09	b	3.57 ± 0.32	a	1.00 ± 0.10	a
(2.5 t ash + 180 kg/N)/ha	n.d.		n.d.		n.d.		n.d.		n.d.	
Optimal concentrations obtained for Lithuanian conditions (Vaicys et al. 1979)	15–16		1.0–1.3		4.5–6.0		0.5–3.0		0.6–1.2	
Normal range of the concentrations (Abrahamsen 1980; Chapin, Van Cleve 1989)	7–16		0.6–0.9		3.0		0.5		0.6	
Critical levels of deficiency for concentrations (Braekke 1996)	12–15		1.2–1.5		3.5–5.5		0.4–0.7		0.4–0.8	
Range of macronutrient values in classes 1 to 3 at a European level (Stefan et al. 1997)	12–17		1.0–2.0		3.5–10.0		1.5–4.0		0.6–1.5	
Optimal nutritional status based on nutritional class III (Krauβ, Heinsdorf 2005)	15.8–20.6		0.79–1.26		4.1–5.2		2.1–3.1		0.6–0.9	

* n.d. – no data

and N fertilization were found for Mg concentrations in the needles.

The changes in nutrient availability in soil and the ability to accumulate the elements in different parts of the tree could also be influenced by the fertilization and vary from case to case. The most increased tree growth was found in the plots which were fertilized with ash together with nitrogen (Ozolinčius et al. 2007b). The current year needle mass increased from 1.34 kg (in the control) to 1.89 kg (N treatment) and even to 2.17 kg (ash together with N). The mass changes of the first year needles were smaller: the mass increased 1.4–1.5 times in N treatment, and by about 52% in the ash together with N plots.

1.2–1.3 times higher N, and 9–10% higher amounts (concentration per dry mass unit) of P were found in the current and first year needles in the plots treated with nitrogen (Fig. 3). K amounts, however, did not differ between the treatments. The application of N fertilizers decreased the amount of K by 20% in the current year needles, while in older needles it increased from 6.6 ± 1.0 g to 7.1 ± 0.6 g as an average per tree. All the results varied in uncertainty range, with the exception of Mg content that markedly increased in both ash and N treated plots.

The applied relatively small amounts of the nutrients with ash (10.8 kg/P/ha, 26.5 kg/K/ha, 360.2 kg/Ca/ha) had an insignificant impact on the pine needle chemical composition and its contents in most cases. The application of wood ash slightly increased P by 5%, K by 5–10% and Ca by about 10–30% in both current and first year needles. Still, the data varied in uncertainty range. Curiously, the applied amount of Mg with wood ash (47.3 kg/Mg/ha) significantly increased the Mg content (more than 6 times) (Fig. 3).

Nutrient concentrations in comparison with optimal values

For the evaluation of needle nutrition data, it is reasonable to compare nutrient concentrations with the optimal amount, critical levels of deficiency or target levels for ratios to N. Different authors indicate some variations of optimal nutrient concentrations (Abrahamsen 1980; Chapin, Van Cleve 1989; Braekke 1996) or group them into the classes based on the different concentration ranges (Krauβ, Heinsdorf 2005). According to the study of Krauβ and Heinsdorf (2005), the optimal nutritional status of different nutrient requirements of Scots pine is based on nutritional class III, and comprises on average 18 mg/N/g, 1.0 mg/P/g, 4.6 mg/K/g, 2.5 mg/Ca/g and 0.75 mg/Mg/g. Optimal values for Scots pine growing in Lithuanian conditions were also determined by Vaičys et al. (1979). These values on average correspond to the values obtained by other authors (see Table 2).

The macronutrient values in Scots pine foliage should also be evaluated at the European level. Such classification values of N, P, K, Ca and Mg were fixed at the 3rd Forest Foliar Expert Panel Meeting (Stefan et al. 1997). Using the classification of 3 classes, where class 2 corresponds to normal to adequate nutrient concentrations (Table 2), we found that our values in most of the cases were in the range between low and high concentrations. For N concentration, the fertilization with 180 kg/N/ha gave a positive response and optimally increased the N value. In comparison with the optimum K value, the K concentrations in pine needles in control and fertilized plots were low (Class 1).

As it was shown in Table 2, our data corresponded well with the optimal ranges of element concentrations obtained in the literature. In accordance with the classes based on the different concentration ranges (Krauβ, Heinsdorf 2005), N and P concentrations in the pine needles in N fertilized plots were of the same class as or even higher class than in the control in most of the cases. The only difference was found for K concentration, and it belonged to the lowest class (critical level) in the control as well fertilized plots. According to Abrahamsen (1980), Chapin and Van Cleve (1989), Braekke (1996) and other authors, the K concentration could also be treated as slightly lower in the control plots, and the deficiency of this element could potentially be recorded. The deficiency of K is indicated when its value is lower than 3 mg/g (Abrahamsen 1980; Chapin, Van Cleve 1989) or the critical level could be fixed in the range of 3.5–5.5 mg/K/g (Braekke 1996). However, N and P concentrations satisfied optimal values or were higher than critical levels, suggesting that K was limiting for growth.

Nutrient relations

Using the nutrient ratios N/P/K, N/P, K/Ca, Ca+Mg/K or P/N, K/N, Ca/N (Šleinys 1986; Linder 1995; Nilsen, Abrahamsen 2003; Mandre 2003) problems with annual variations are reduced and better evaluation of physiological plant conditions or fertilization effects can be achieved. Linder (1995) suggested nutrient ratios to N that could be treated as an important diagnostic tool.

Our results showed no significant ash influence on P/N, K/N, Ca/N and Mg/N ratios in the current year needles (Table 3). The only difference from the control was observed after the application of ash together with N fertilizers. Here the lowest P, K, Ca and Mg ratios to N were found, compared with the control and other treatments. As an increase in N concentrations in the needles was determined, but K concentrations decreased and P did not change, the N/P/K relations in the control were 69/7/24. In N treated plots the ratio proportions changed to 74/7/19. The ash had no effect on the N/P/K proportions compared with the control.

Vaičys et al. (1979) stated that during a 2-year period after fertilization approximately 9–25% of N, 3–7% P and 6–11% K accumulated in the aboveground Scots pine biomass. Another part of the nutrients applied with fertilizers is leached out (for example leaching amounts to about 20–30% of N fertilizers),

Table 3. Ratios of nutrients to N*100 (%), and relations between N, P and K in the current year needles of Scots pine in treated and control plots 2 years after application

	Target ratio[1]	Limit values[2]	Control	5 t ash/ha	180 kg N/ha	(2.5 t ash + 180 kg N)/ha[5]
P/N	10	10	10.3	10.4	9.9	8.2*
K/N	35	30	34.5	30.3	24.9*	21.0
Ca/N	2.5	4	15.9	19.9	18.1	14.5
Mg/N	4	4	8.9	10.4	8.2	6.6
N/P/K	71/7/22[3] 67/7/26[4]		69/7/24	71/7/22	74/7/19	78/6/16

[1]Linder (1995); [2]Braekke et al. (1998); [3]Šleinys (1986); [4]Vaičys et al. (1979); [5]data was sampled 5 months after the treatment; no comparable data after 2 years is available, *significant difference from the control during the sampling period indicated by $P < 0.05$

about 10–18% is taken up by the ground vegetation and 30–50% is used by the sorption of soil organic compounds (Vaičys et al. 1979). Helmisaari et al. (2002) indicated that annually total biomass could accumulate approximately 45–63% of N of its total pool in the soil. Then, about 27–34% of N could be taken up for the growth of the current year needles and only 2–3% of the total amount in the soil goes to stem wood. To accept the above-mentioned tendency, in all the cases we discuss only about one third of the nutrients available to plants. Therefore, we need to clarify the tree response to fertilization when taking into account the changes in the soil nutrient composition.

Graphical analyses for examining the tree response to a treatment

The graphical analysis was done to evaluate the nutrient status by examining the tree response to a treatment. The application of wood ash and N fertilizers increased the mass of the current year needles, and higher N and P concentrations were found (C-shift) (Fig. 4), whereas N and P concentra-

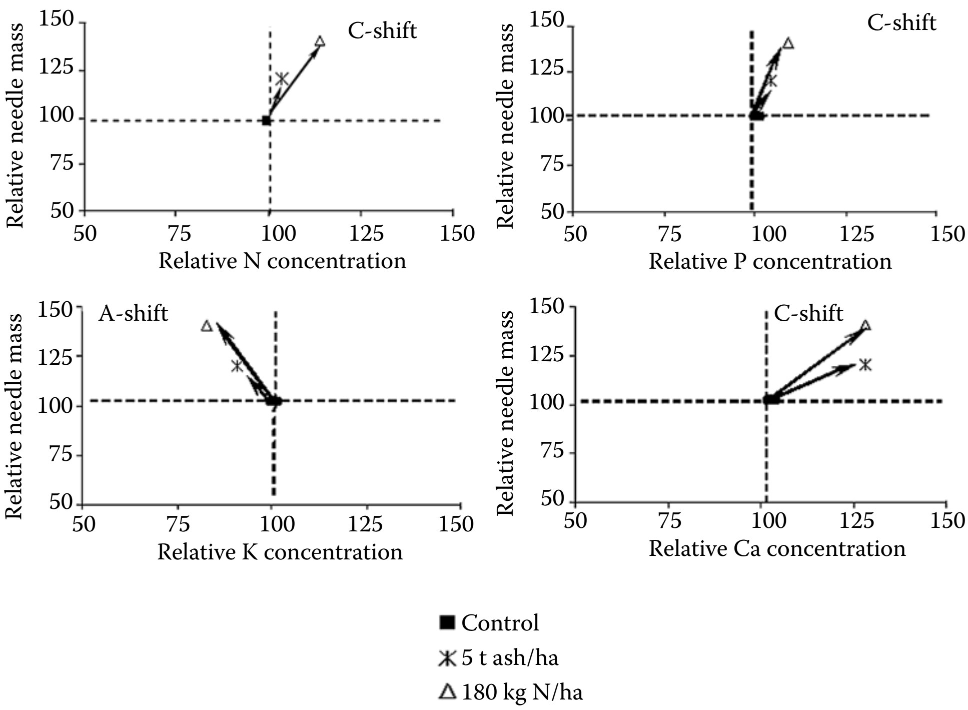


Fig. 4. Effects of wood ash and nitrogen treatments, shown as responses relative to the untreated control (100, 100), on the concentrations of N, P, K, Ca and Mg and needle mass for Scots pine. Vectors are shown for A- and C-shifts (the modified graphical representation of diagnoses according to Timmer and Morrow 1984)

tions in the soil before treatment could be a limiting factor for the pine growth. However, the K concentrations decreased when the needle mass increased after fertilization (A-shift). Consequently, it could be suggested that potassium was not the growth limiting element before treatment, yet it was weakly available to pine trees. Similar consistencies were determined by Nilsen and Abrahamsen (2003) in the experiment where N fertilization increased N concentration but decreased K in the needles. The changes in potassium in the wood ash plots could be caused by the antagonistic influence of Ca ions applied with ash, which blocked the availability of K cations (Kučinskas et al. 1999). Similarly, Tyler and Olsson (2001) found that the concurrence of K ions with Ca in more alkaline soils decreased the availability of K^+. Our data showed that the concentration of Ca ions significantly increased by 25–30% in the current year needles in a 2-year period after the ash fertilization. The highest difference from the control was determined a few months after the ash treatment when Ca concentration increased from 1.80 ± 0.16 g/kg (in the control) to 2.61 ± 0.22 g/kg (5 t ash per ha) in the needles. Besides, the K concentration in the current year needles was quite low (according to Abrahamsen 1980; Chapin, Van Cleve 1989; Braekke 1996) in the control plots, so its deficiency could also occur before treatment.

Correlation of nutrient concentrations in needles and soil

When fertilization is used, we expect the best plant response and increased growth, however, the nutrient pools in the soil show only the potential soil reserve of nutrients, and the nutrient amount in the needles does not always depend on their amount in the soil or sometimes it depends on it very weakly (Ingerslev 1998). For instance, after the application of N fertilizers, i.e. when the concentration of N increased in the forest floor and mineral topsoil, there is a tendency of its increase in the needles (Fig. 5).

Ingerslev (1998) also noted that the nutrient concentrations in the needles more often depended on their concentrations in the soil solution. However, our scarce data showed no dependence between the concentration of N in the soil solution and in the current year needles (Fig. 6). After the fertilization with ash and nitrogen, only a slight tendency could be seen. When there was a lower N concentration in the soil solution, only a slight N increase in the needles could be found.

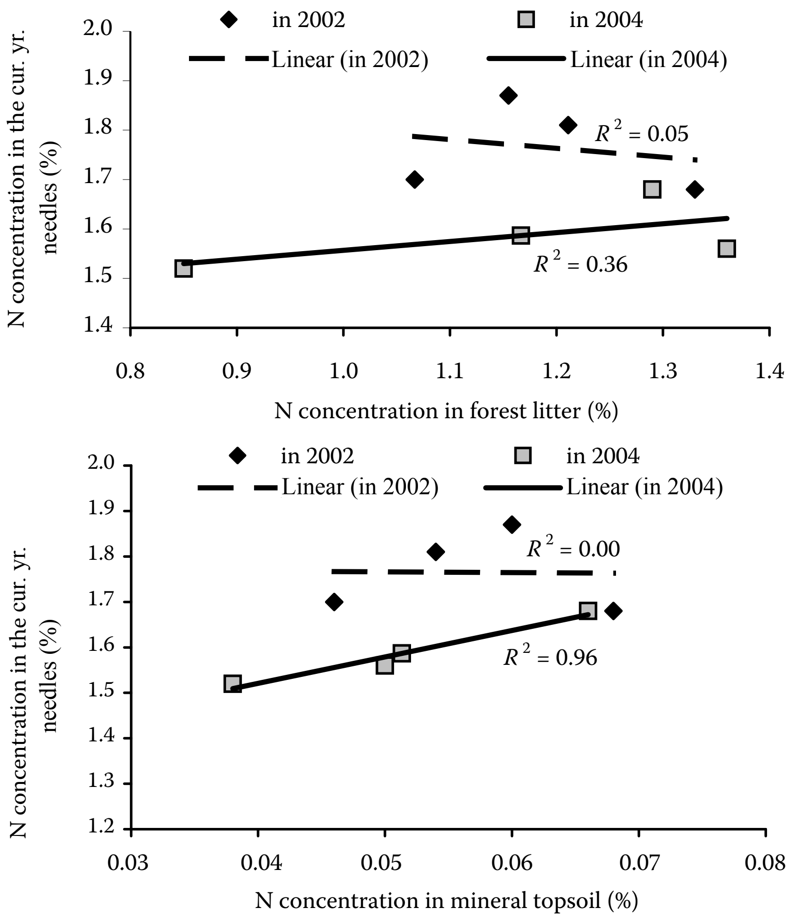


Fig. 5. Correlations of N concentrations in the current year needles, soil organic layer and mineral topsoil (0–5 cm depth) in the comparable N fertilized plots

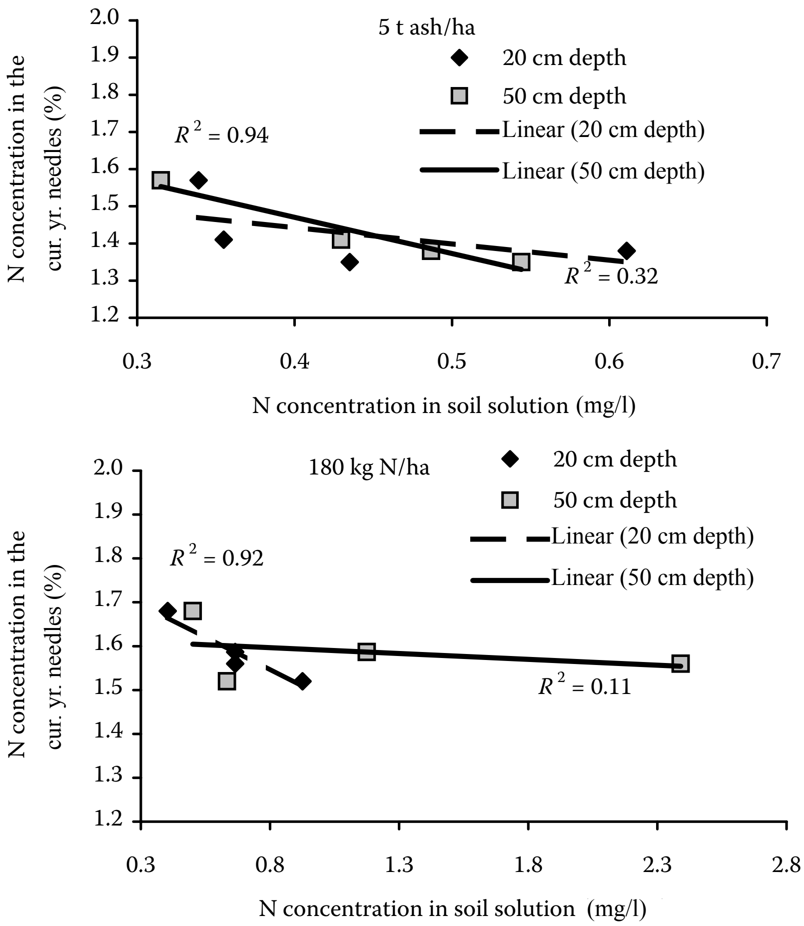


Fig. 6. Correlations of N concentrations in the current year needles and in the soil solution at 20 and 50 cm depths in the comparable plots fertilized with wood ash and nitrogen

It was quite complicated to find any correlation of N concentration in the current year needles with comparable concentration of the chlorophylls *a* and *b* in the needles in the plots fertilized with wood ash and nitrogen. Looking for a reliable treatment response, the vitality indicator, crown defoliation, was also examined in correlation with the needles nutrient status. Therefore, the mean crown defoliation did not change under the influence of wood ash nor N fertilizers possibly due to a very short time (2 years) after the treatment. The mean pine defoliation was 20.6 ± 2.0% in the control, it slightly increased in ash plots (21.7 ± 1.7%) and decreased in N plots (18.9 ± 1.1) (personal communication). There were no possibilities to indicate the significant correlation of the response with the needles nutrient status.

CONCLUSIONS

The analyses of the foliage nutrient status in the Scots pine stand when wood ash with/without N was recycled to the forest showed that the best initial tool for the response evaluation was the significance analyses of the changes in the nutrient composition in the soil and needles. The comparison of nutrient concentrations with optimal amounts, critical levels of deficiency or target levels for ratios to N, and applied graphical analyses, could also provide possible indications in the soil-plant relation. A much lower indication was found when the correlation analyses of the nutrient concentrations in soil needles and soil were applied.

1. Only N fertilization significantly influenced the growth and nutrition of Scots pine needles. A major increase in the concentration of N and its content occurred in the current and second year needles. The concentration of P also increased in the needles in N fertilized plots. The increase in other nutrients can be explained by the specific internal nutrient mechanisms which regulate balanced nutrient amounts in the soil that consequently cause nutrient availability to plants.
2. When the needles nutrient status was evaluated, only K concentrations were considered to be low, and a potential deficiency could occur in the control plots. On the contrary, the concentrations of N and P corresponded to or exceeded the mean critical values.
3. The graphical analysis indicated that K concentrations relatively decreased when the needle mass increased after the ash fertilization. This could be caused by the antagonistic influence of Ca ions applied with ash, which blocked the availability of K cations.

4. The application of N fertilizers increased N concentration in the forest floor and mineral topsoil, and as a result there occurred a tendency of N increase in the needles. No correlations in the other treatments were obtained.
5. The lowest P, K, Ca and Mg ratios to N were found in the plots treated with wood ash together with N fertilizers, compared with the control and other treatments.

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References

ABRAHAMSEN G., 1980. Acid precipitation, plant nutrients and forest growth. In: DRABLOS D., TOLLAN A. (eds), Proceedings, International Conference Ecological Impact of Acid Precipitation Norway. SNSF Project: 58–62.

BRAEKKE F.H., 1996. Needle analyses and graphic vector analyses of Norway spruce and Scots pine stands. Trees, *11*: 23–33.

BRAEKKE F., SALIH N., INGERSLEV M., 1998. Nutrient status of stands – needle analyses. In: ANDERSSON F., BRAEKKE F., HALLBÄCKEN L. (eds), Nutrition and Growth of Norway Spruce Forests in a Nordic Climatic and Deposition Gradient. Nordic Council of Ministers, Forestry, Tema Nord: 556.

BRAMRYD T., FRANSMAN B.O., 1995. Silvicultural use of wood ashes – effects on the nutrient and heavy metal balance in a pine (*Pinus sylvestris* L.) forest soil. Water, Air and Soil Pollution, *85*: 1039–1044.

CHAPIN F.S. III, VAN CLEVE K., 1989. Approaches to studying nutrient uptake, use and loss in plants. Plant Physiological Ecology (Field Methods and Instrumentation): 185–207.

ERIKSSON H.M., 1998. Short-term effects of granulated wood ash on forest soil chemistry in SW and NE Sweden. Scandinavian Journal of Forest Research, *2*: 43–55.

HELMISAARI H.S., MAKKONEN K., KELLOMÄKI S., VALTONEN E., MÄLKÖNEN E., 2002. Below- and above-ground biomass, production and nitrogen use in Scots pine stands in Eastern Finland. Forest Ecology and Management, *165*: 317–326.

INGERSLEV M., 1998. Vitalization of mature Norway spruce stands by fertilization and liming. The Research Series, Vol. 23. Hørsholm, Danish Forest and Landscape Research Institute: 126.

INGESTAD T., 1979. Mineral nutrient requirements of *Pinus sylvestris* and *Picea abies* seedlings. Physiologia Plantarum, *45*: 373–380.

ISSS-ISRIC-FAO, 1998. World reference base for soil resources. Rome, FAO. World Soil Resources Report, *84*: 1–81.

JACOBSON S., KUKKOLA M., MÄLKÖNEN E., TVEITE B., 2000. Impact of whole tree harvesting and compensatory fertilization on growth of coniferous thinning stands. Forest Ecology and Management, *129*: 41–51.

KAIRIŪKŠTIS L., JASKELEVIČIUS B., 2003. Forest energy resources and their utilization in Lithuania. Baltic Forestry, *9*: 29–41.

KELLNER O., WEIBULL H., 1998. Effects of wood ash on bryophytes and lichens in a Swedish pine forest. Scandinavian Journal of Forest Research, Supplement, *2*: 76–85.

KRAUβ H.H., HEINSDORF D., 2005. Ernährungsstufen für wichtige Wirtschaftsbaumarten. Beiträge für Forstwirtschaft und Landschaftsökologie, *39*: 172–179. (In German with English summary)

KUČINSKAS J., PEKARSKAS J., PRANCKIETIENĖ I., VAIŠVILA Z.J., ŽEMAITIS A., 1999. Agrochemistry. Kaunas, Lututė: 338. (In Lithuanian)

LEVULA T., SAARSALMI A., RANTAVAARA A., 2000. Effects of ash fertilization and prescribed burning on macronutrient, heavy metal, sulphur and ^{137}Cs concentrations in lingonberries (*Vaccinium vitis-idaea*). Forest Ecology and Management, *126*: 269–279.

LICHTENTHALER K., 1978. Chlorophylls and Carotenoides: Pigments of Photosynthetic Bromembrans. Methods in Enzymology, *148*: 351–382.

LINDER S., 1995. Foliar analysis for detecting and correcting nutrient imbalances in forest stands. Ecological Bulletin (Copenhagen), *44*: 178–190.

LJUNG A., NORDIN A., 1997. Theoretical feasibility for ecological biomass ash recirculation: Chemical equilibrium behavior of nutrient elements and heavy metals during combustion. Environmental Science & Technology, *31*: 2499–2503.

MANDRE M., 2003. Conditions for mineral nutrition and content of nutrients in Scots pine (*Pinus sylvestris*) on dunes in Southwest Estonia. Metsanduslikud Uurimused (Forestry Studies), *39*: 32–42.

MANDRE M., PÄRN H., OTS K., 2006. Short-term effects of wood ash in the soil and the lignin concentration and growth of *Pinus sylvestris* L. Forest Ecology and Management, *223*: 349–357.

MIKŠYS V., VARNAGIRYTĖ-KABAŠINSKIENĖ I., MØLLER I.S., ARMOLAITIS K., KUKKOLA M., WÓJCIK J., 2007. Above-ground biomass functions for Scots pine in Lithuania. Biomass & Bioenergy, *31*: 685–692.

MOILANEN M., ISSAKAINEN J., 2000. Effects of wood ash on forests. Metsätehon raportti, *93*: 18.

NILSEN P., ABRAHAMSEN G., 2003. Scots pine and Norway spruce stands responses to annual N, P and Mg fertilization. Forest Ecology and Management, *174*: 221–232.

OHNO T., ERICH M.S., 1990. Effect of wood ash application on soil pH and soil test nutrient levels. Agriculture, Ecosystems and Environment, *32*: 223–239.

OZOLINČIUS R., ARMOLAITIS K., RAGUOTIS A., VARNAGIRYTĖ I., ZENKOVAITĖ J., 2006. Influence of wood ash recycling on chemical and biological condition of forest Arenosols. Journal of Forest Science, *52*: 79–86.

OZOLINČIUS R., VARNAGIRYTĖ-KABAŠINSKIENĖ I., ARMOLAITIS K., GAITNIEKS T., BUOŽYTĖ R., RAGUOTIS A., SKUODIENĖ L., ALEINIKOVIENĖ J., STAKĖNAS V., 2007a. Initial influence of compensatory wood ash fertilization on soil, ground vegetation and tree foliage in Scots pine stands. Baltic Forestry, *13*: 158–168.

OZOLINČIUS R., VARNAGIRYTĖ-KABAŠINSKIENĖ I., STAKĖNAS V., MIKŠYS V., 2007b. Effects of wood ash and nitrogen fertilization on Scots pine crown biomass. Biomass & Bioenergy, *31*: 700–709.

PÄRN H., 2005. Effect of wood ash application on radial and height growth of young Scots pines (*Pinus sylvestris* L.). Metsanduslikud Uurimused (Forestry Studies), *42*: 48–57.

SAARSALMI A., MÄLKÖNEN E., 2001. Forest fertilization research in Finland: a literature review. Scandinavian Journal of Forest Research, *16*: 514–535.

SAARSALMI A., MÄLKÖNEN E., PĨĨRAINEN S., 2001. Effects of wood ash fertilization on forest soil chemical properties. Silva Fennica, *35*: 355–368.

SAARSALMI A., DEROME J., LEVULA T., 2005. Effect of wood ash fertilization on stand growth, soil, water and needle chemistry, and berry yields of lingonberry (*Vaccinium vitis-idaea* L.) in Scots pine stand in Finland. Metsanduslikud Uurimused (Forestry Studies), *42*: 13–34.

SAARSALMI A., KUKKOLA M., MOILANEN M., AROLA M., 2006. Long-term effects of ash and N fertilization on stand growth, tree nutrient status and soil chemistry in a Scots pine stand. Forest Ecology and Management, *235*: 116–128.

ŠLEINYS R., 1986. Pedological-ecological parameters of soil mineral nutrition and its optimization in Scots pine stands. [Summary of Ph.D. Thesis.] Tartu: 48. (In Russian)

STEFAN K., FÜRST A., HACKER R., BARTELS U., 1997. Forest Foliar Condition in Europe – Results of large-scale foliar chemistry surveys. EC, UN/ECE, Austrian Federal Forest Research Centre: 207.

THELIN G., 2000. Nutrient imbalance in Norway spruce. [Ph.D. Thesis.] Lund University: 44.

THELIN G., ROSENGREN-BRINCK U., NIHLGARD B., 1999. Can graphical vector analysis be used to identify micro nutrient deficiency? Water, Air, and Soil Pollution, *116*: 383–388.

TIMMER V.R., MORROW L.D., 1984. Predicting fertilizer growth response and nutrient status of jack pine by foliar diagnoses. In: STONE E.L. (ed.), Forest Soils and Treatment Impact. Sixth North American Forest Soils Conference. Knoxville, Department of Forestry, Wildlife, and Fishery, University of Tennessee: 335–352.

TYLER G., OLSSON T., 2001. Concentrations of 60 elements in the soil solution as related to the soil acidity. European Journal of Soil Science, *52*: 151–165.

UN/ECE, 2000. Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Part IV. Sampling and Analysis of Needles and Leaves. Hamburg, Geneva, Programme Coordinating Centre: 1–37.

UN/ECE, 2002. Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Part IIIb. Soil solution collection and analysis. Hamburg, Geneva, Programme Coordinating Centre: 109–161.

UN/ECE, 2003. Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Part IIIa. Sampling and analyses of soil. Hamburg, Geneva, Programme Coordinating Centre: 1–108.

VAIČYS M., RAGUOTIS A., ŠLEINYS R. 1979. Manual of forest soils. Mokslas: 200. (In Lithuanian)

WILLIAMS T.M., HOLLIS C.A., SMITH B.R., 1996. Forest soil and water chemistry following bark boiler bottom ash application. Journal of Environmental Quality, *25*: 955–961.

WILSON F.R., FARRELL E.P., 2007. The use of foliage and soil information for managing the nutrition of Sitka and Norway spruce on cutaway peatlands. Silva Fennica, *41*: 409–424.

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Stav výživy porostů borovice lesní přihnojené dřevěným popelem zjišťovaný listovými analýzami

ABSTRAKT: Účinek přihnojení dřevěným popelem a dusíkatým hnojivem na růst porostu borovice lesní byl zjišťován v Litvě. Cílem práce bylo vyhodnocení listových a půdních analýz jako potenciálních indikátorů vztahů mezi půdou a dřevinami v porostu. Za nejlepší způsob hodnocení výsledků listových analýz zjišťujících stav výživy porostů borovice lesní je považována analýza změn v obsahu živin v listech a růstu stromů, které přihnojení vyvolává. Z trendu změn jsou obsahy živin posuzovány jako optimální, deficitní nebo nadbytečné.

Klíčová slova: jehlice borovice lesní; dřevěný popel; dusík; olistění; živiny

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